Radiation Facts About the Jupiter Europa Orbiter (JEO) Mission

Spacecraft to Jupiter's inner magnetosphere must use a combination of natural and man-made radiation mitigation strategies to operate successfully over many years.

What is the radiation environment like near Europa's orbit?

Like Earth's Van Allen radiation belts, Jupiter's intense belts of ions and electrons are spatially confined in a torus encircling the planet. The greatest threat to spacecraft systems are the ions and electrons in the hundreds of keV to tens of MeV energy range. Analyses of the inner regions of Jupiter's magnetosphere have shown that these particles have fairly consistent intensities over time [1]. Storm-like and other disruptive transient events have been observed to occur. Storms caused, for instance, by changes at the sun and throughout the heliosphere can perturb the magnetosphere greatly. However, the data from Galileo indicate that these events do not affect the overall fluence significantly. Therefore, the total dose to the spacecraft in the inner region is predictable.

How do we ensure the instruments will operate?

JPL has accumulated years of experience in designing instruments and ensuring their operations near Jupiter. To date there have been seven flybys of Jupiter by spacecraft (Pioneer 10 and 11, Voyager 1 and 2, Ulysses, Cassini, and New Horizons) as well as an orbiter, Galileo. The project has developed a reference model to estimate the effects of that planet's radiation environment on different instruments and spacecraft systems. In FY'08, a Detector Working Group was formed to assess the susceptibility of notional instruments under the harsh radiation environment. A scientific quality image has been demonstrated under simulated heavy radiation conditions.

What are the natural forms of radiation mitigation?

The easiest way to lessen the total dose is to limit the amount of time in the belts themselves. Galileo employed an orbit that included a low perijove for satellite flybys and a large apojove. Even so, it spent many weeks in the radiation belts: the first encounter was with Io on Dec. 7, 1995 and the last was with Amalthea on Nov. 5, 2002. Juno will spend some time on the magnetic field lines connecting to the radiation belts, but will travel mostly on polar field lines, (which map outside the belts), and at low Jovian altitude, essentially under the belts.

Europa is situated well inside the electron radiation belt; thus, simply avoiding the belts is not an option for JEO. JEO would orbit Jupiter for 2.5 to 3 years prior to inserting into Europan orbit and would receive a radiation dose similar to that of the Galileo orbiter. Also like Galileo, the dose accumulates most rapidly in the regions closest to Jupiter, near the orbits of Io and Europa.

The Divine and Garrett model, with the GIRE update [2], is the standard model used to estimate the radiation dose a spacecraft receives during its lifetime. Using the model, a Total Ionizing Dose (TID) can be computed, given the spacecraft trajectory through the environment. (Experience with Galileo indicates that this model probably overestimates the total dose.) Although other types of radiation effects, such as single event upsets, can transiently affect functionality, we are focusing on TID because its accumulation influences mission feasibility.

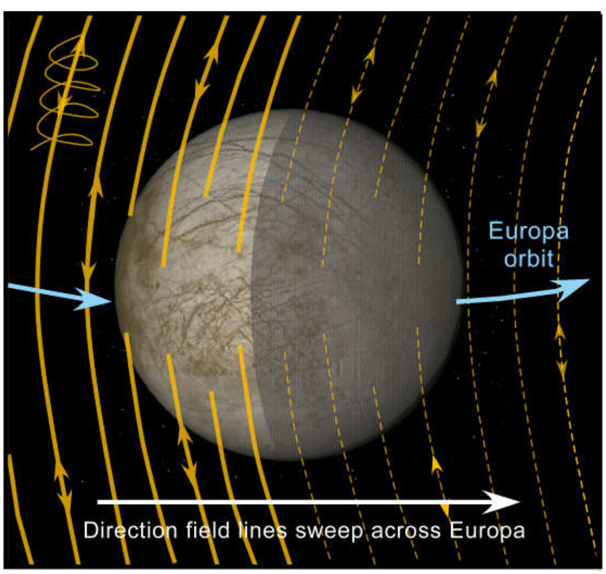

Figure 1. Energy is deposited into Europa's trailing hemisphere as plasma overtakes the moon. The depleted field lines result inan energy-dependent "shadow" lowering the radiation environment on Europa's leading hemisphere.

GIRE is a global model not intended to account for strategies such as shielding of the spacecraft by the moon itself, which has always been done to mitigate the total dose predicted. The protection afforded to the spacecraft by a moon can be quite substantial in a low altitude orbit as seen by considering the dimensions: R_E = 1560 km and R_{SC} = 100–200 km. Since the spacecraft would be in orbit for months, this correction to the TID is critical. Our best estimate to date of the "radiation shadow" cast by Europa (Fig. 1) involves the following principles. In considering dose, energetic electrons penetrate deepest into materials and as they slow, they emit photons (bremsstrahlung, or "braking" radiation) that deposit energy even deeper. Electrons are therefore hard to shield out except by using a lot of heavy material on the spacecraft. But near Europa, electrons travel with high velocities along magnetic field lines (in the north/south direction at Europa) and very slowly in the perpendicular directions. Therefore, electrons spiraling up and down the field lines hit Europa as soon as the field lines come into contact with it. Energetic electrons are therefore heavily lost near the equatorial trailing hemisphere of the moon leaving flux tubes very depleted of these electrons over much of Europa's surface. This creates a kind of shadow; the exact dimensions of which depend on electron energy. The **JEO would spend about *half its time in this shadow*** and so ***would experience significantly less radiation*** than it would receive in free space [3]. In summary, the moon would provide a great deal of the shielding that would otherwise be needed on the spacecraft itself.

What does this mean for JEO total dose?

Analysis of total mission radiation dose including the Europa shadowing effect results in a TID estimate of 2.9 Mrad behind 100 mils of Al (Fig. 2) and in a high confidence level that the spacecraft would be fully functional at 1 year. This approach was peer reviewed by non-project personnel in six separate reviews in 2007 and was endorsed and updated per inputs from specialists [4].

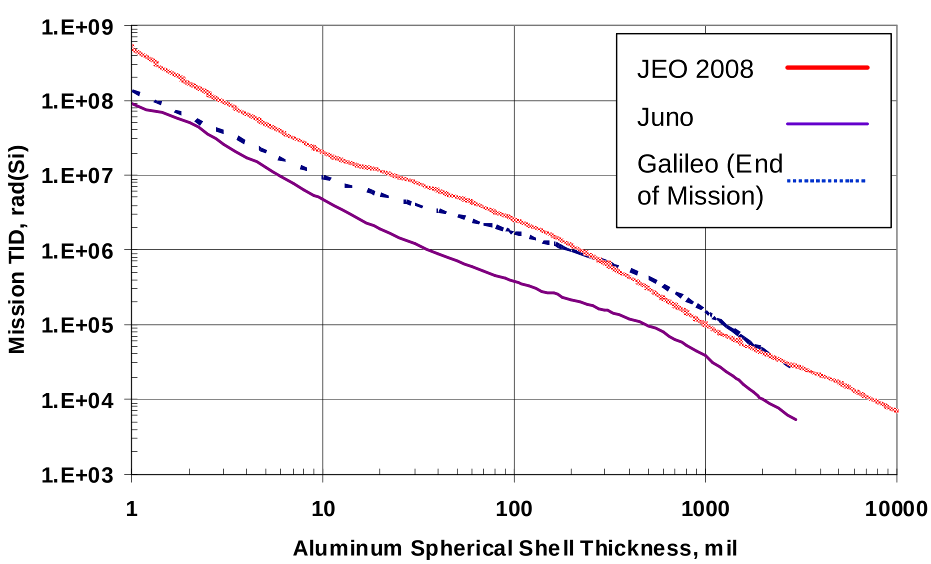

Figure 2. Estimated Total Mission Ionizing Dose vs. Shell (Al) Thickness — Estimated dose depth curves for Juno, Galileo, and Jupiter Europa Orbiter indicate that the estimated Galileo actual experience is close to the expected design environment for the primary Jupiter Europa Orbiter mission.

How do we shield for this?

A thick enclosure of material (usually chosen for high density for packaging efficiency) can shield components (sensor heads, electronics, materials, etc.) from the harmful effects of the radiation environment. Conservative JPL design practices dictate that components are shielded such that they "see" only one-half the part capability.

What is the shielding strategy and how does it compare with that of Juno and Galileo?

JEO handles the radiation environment using a combination of radiation-hardened parts and key component shielding. Juno uses non-hardened, or "radiation-soft" parts (10–50 krad), and a single large "vault" (~160 kg of tantalum and aluminum shielding) designed to reduce the environment at the electronics to one-half the part capability.

Using the Juno approach for JEO, which expects approximately 5 times the TID, would require an inordinate amount of mass. In contrast, the primary radiation-mitigation strategy for JEO is to use more radiation-hard parts (100–1000 krad). In addition, instead of a single vault, JEO uses multiple enclosures where the shielding is tailored for specific part capability, resulting in a manageable total of ~180 kg of tungsten/copper shielding. This JEO approach is similar to Galileo's.

Are the needed rad-hard parts available now?

Yes, key parts are available and have required heritage. Recent advances in electronics for military and nuclear applications have made many parts available from 100 – 1000 krad(Si). High Speed PWM chips up to 1 MRad(Si) are commercially available. They were developed under the NASA Mars Exploration Program in partnership with JHU/APL. Radiation hardened ASICs have been flight qualified and flown. Other key components such as processors, memory, detectors, bus interface chips, and ADCs are available from 300 krad to 1 Mrad from many qualified commercial vendors.

What help is going to be available?

The project would develop and provide design guidelines and other information for prospective suppliers of components, including instruments which would be required to operate in the harsh radiation environment. Additionally, the project is testing, assessing, and compiling radiation data on high-profile parts; detectors, sensors, microprocessors, memory, FPGAs/ASICs, interface parts, ADCs/DACs, and power converters would be included in an Approved Parts and Materials List to be initially released in Fall 2008.

References:

[1] Europa Explorer Radiation Issue Report, JPL D-34103, April 4, 2006.

[2] Garrett, H.B., I. Jun, J.M. Ratliff, R.W. Evans, G.A. Clough, and R.E. McEntire, Galileo interim radiation electron model, JPL Publication 03-006 (2003).

[3] Paranicas, C., B.H. Mauk, K. Khurana, I. Jun, H. Garrett, N. Krupp, and E. Roussos, Europa's near-surface radiation environment, *Geophys. Res. Lett.,* 34, L15103, doi:10.1029/2007GL030834 (2007).

[4] 2007 Europa Explorer Mission Study Report: Final Report, JPL D-41283, dated November 1, 2007 (especially Appendix C—Radiation Assessment Report which describes Peer Reviews conducted in 2007).